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Phase Structure and Magnetic Properties of Fe-Nb-B-Pt Type of Bulk Nanocrystalline Alloys

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The paper refers to magnetic and structure properties of the $(Fe_{80}Nb_6B_{14})_{1-x}Pt_x$ ($x = 0.15$, 0.3, 0.4 and 0.6) bulk nanocrystalline alloys prepared using the vacuum suction casting technique. The samples were in the form of rods with diameters ranging from 0.5 mm to 1.5 mm. It was shown that the optimal Pt content is $x = 0.4$ with the coercive field equal to 0.2 T and maximum energy product $|BH|_{max} = 11.2$ kJ/m^3. The magnetic properties can be associated with Fe-Pt, Fe and Fe-B phases, depending on the alloy composition.

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1. Introduction

A progress in modern technologies requires new materials with specific properties for different kind of applications. In the field of magnetism among well known permanent magnets, such as Co-Sm, Fe-Pt or Fe-B-Tb types of compounds [1, 2], very promising are Fe-Nb-B type nanocrystalline alloys. It is well known that such alloys exhibit, in a comparison with their crystalline form, unique and mostly superior magnetic properties [3]. From practical point of view especially interesting are nanocrystalline alloys in the so-called bulk form i.e. rods, ingots etc. with dimensions of the order of several mm [4]. Recently, we have reported structural and magnetic properties of $(Fe_{80}Nb_6B_{14})_{1-x}M_x$ (M=Au, Ni, Gd, Tb) bulk nanocrystalline alloys prepared by vacuum suction casting technique [5]. These preliminary studies reveal that the alloys with Tb can be considered as high coercive magnetic materials [6], but values of saturation magnetization M_S are relatively low due to antiferromagnetic coupling between Fe and Tb. Therefore, the aim of this work is to study the phase structure and magnetic properties of the $(Fe_{80}Nb_6B_{14})_{1-x}Pt_x$ ($x = 0.15$, 0.3, 0.4, 0.6) bulk alloys prepared by vacuum suction casting technique. The study concerns the as cast samples and the influence of cooling rate on magnetic properties was investigated.

2. Experimental procedure

The $(Fe_{80}Nb_6B_{14})_{1-x}Pt_x$ ($x = 0.15$, 0.3, 0.4 and 0.6) bulk nanocrystalline alloys were prepared using the vacuum suction casting technique (described in [4]). The samples were in the form of rods with diameters $d =$ 1.5 mm and about 3 cm in length. Moreover, for the $(Fe_{80}Nb_6B_{14})_{0.6}Pt_{0.4}$ compound the samples with additional diameter $d = 1$ mm and $d = 0.5$ mm were also prepared. Magnetic properties were tested by means of SQUID magnetometer (XL-7, Quantum Design) in magnetic fields up to 7 T and temperatures 2 K – 300 K. Phase identification was performed with the use of X-ray diffraction (PANalytical Empyrean) using Cu K$_\alpha$ radiation.

3. Results and discussion

Figure 1 presents magnetic hysteresis loops measured at room temperature for the samples of 1.5 mm in diameter and $x = 0.15$, 0.3, 0.4, 0.6. At room temperature, the best hard magnetic properties are obtained for the $(Fe_{80}Nb_6B_{14})_{0.6}Pt_{0.4}$ compound with coercive field μ_0H_C, saturation magnetization M_S and maximum energy product $|BH|_{max}$ equal to 0.2 T, 67 A·m^2/kg and 11.2 kJ/m^3, respectively. In the case of the alloys with lower ($x = 0.15$, 0.3) Pt content the higher values of M_S (up to 75 A·m^2/kg for $x = 0.3$) were observed, however with relatively low coercive field about 0.02 T. The $(Fe_{80}Nb_6B_{14})_{0.4}Pt_{0.6}$ compound can be characterized by the coercive field equal to 0.03 T and a lower value of

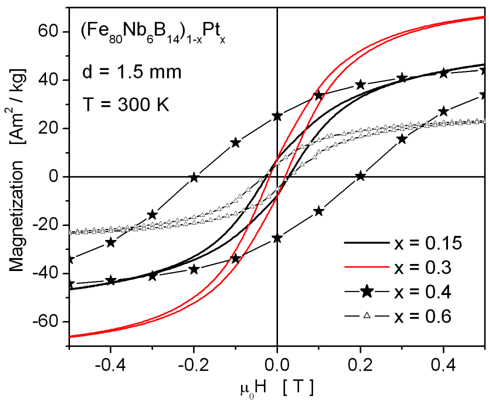

Fig. 1. Hysteresis loops for the $(Fe_{80}Nb_6B_{14})_{1-x}Pt_x$ alloys with $d = 1.5$ mm, measured at 300 K.

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saturation magnetization (31 A·m^2/kg) due to the low iron content. Figures 2 and 3 present magnetic hysteresis loops of $(Fe_{80}Nb_6B_{14})_{0.6}Pt_{0.4}$ alloy determined for different d values and at different measurement temperature T, respectively. As it is shown, changing of diameter value does not causes remarkable changes of the magnetic properties. As one can expect, the decrease of measurement temperature T leads to higher values of $\mu_0 H_C$ (up to 0.27 T) and M_S (up to 70 A·m^2/kg), determined at 2 K. The magnetic properties including coercive field $\mu_0 H_C$, saturation magnetization M_S (determined at the highest H value) and remanence M_r values with the phase structure content (determined based on the X-ray diffraction) for all investigated alloys are listed in Table. For all studied alloys, the main magnetic phase fcc-FePt (A1) has face centered cubic structure which is magnetically relatively soft. Moreover, from broadening of diffraction peaks (not shown here) the mean diameters of the crystallites were estimated to be about 10 nm for all examined cases.

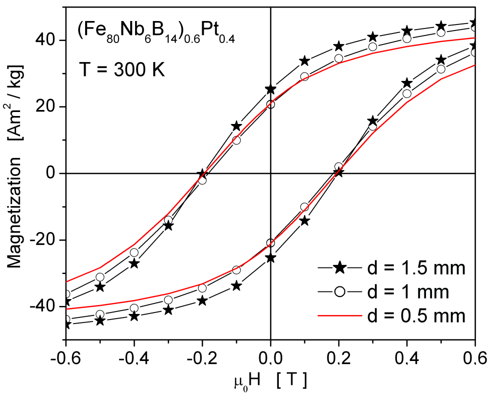

Fig. 2. Hysteresis loops for the $(Fe_{80}Nb_6B_{14})_{0.6}Pt_{0.4}$ alloy samples with different diameters.

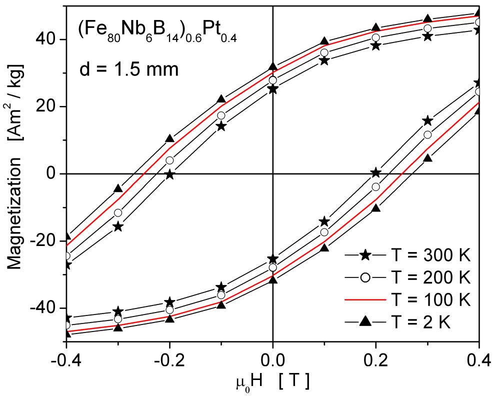

Fig. 3. Hysteresis loops for the $(Fe_{80}Nb_6B_{14})_{0.4}Pt_{0.6}$ alloy sample with d = 1.5 mm, measured at different temperatures.

Let's note that in the case of the alloy with 40 at.% of Pt the observed magnetic hardening is rather connected with a specific nanostructure than with the formed phases. Moreover, the phase composition does not depend on the sample diameter which is consistent with the magnetic measurements. In contrast to this, for the alloys with $x = 0.15$, 0.3 and 0.6 one can observe a mixture of soft magnetic phases as fcc-FePt, α-Fe, Fe_2B and $FePt_3$. It seems that the desired hard magnetic phase, i.e. tetragonal FePt phase (L10) should be formed by an application of heat treatment, that is in our interest and will be studied in the future.

TABLE

Some magnetic parameters determined from the measured hysteresis loops (see the text) and phase structure, detected by XRD.

All. x	d (mm)	$\mu_0 H_C$ (T)	M_s ($\frac{\mathrm{A\,m^2}}{\mathrm{kg}}$)	M_r ($\frac{\mathrm{A\,m^2}}{\mathrm{kg}}$)	Phases
0.15	1.5	0.026	71	7.5	fcc-FePt 2%, Fe 72%, Fe_2B 26%
0.3	1.5	0.019	75	8	fcc-FePt 80%, Fe 9%, Fe_2B 11%
0.4	1.5	0.2	67	25	fcc-FePt 100%
0.4	1	0.182	65	21	fcc-FePt 86%, Fe 2%, $FePt_3$12%
0.4	0.5	0.195	62	21	not measured
0.6	1.5	0.032	31	5.5	fcc-FePt 72%, Fe_2B 28%

4. Conclusions

At this stage of our study, related to the as cast $(Fe_{80}Nb_6B_{14})_{1-x}Pt_x$ bulk nanocrystalline alloys prepared by vacuum suction casting technique, the main conclusions can be summarized as follows.

The as cast bulk nanocrystalline rod consists of a mixture of fcc-FePt, binary iron borides (Fe_2B) and α-Fe phases with mean crystallites diameters of about 10 nm.

The best hard magnetic properties were observed for $x = 0.4$ i.e. $\mu_0 H_c = 0.2$ T and $|BH|_{max} = 11.2$ kJ/m^3.

The magnetic properties seem to be insensitive to the changes in diameter, which means that the obtained cooling rate for applied moulds is not sufficient to change the microstructure of such compounds.

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